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PREDICTED EXTREME HIGH TIDES FOR CALIFORNIA: 1983–2000

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INTRODUCTION

The combination of high tides and storm-induced waves were devastating to the coast of California during the winter of 1982–1983. As property owners began to repair the damage and to consider building various protective structures, questions arose as to how high the tides would be in the future, whether we were entering a new era in Pacific weather, and if sea level was really rising, how fast. Of all these factors, the only one amenable to skillful scientific prediction is the future times and heights of the astronomical tides.

Studies of sea level trends depend primarily on accumulated tide gage data over many years. There is considerable variability from year to year at any station; there are significant regional differences as well. Objective analysis suggests an average global rise in sea level over the past century of about 0.5 ft (0.15 m) (1). Projections of global sea level rise for the next century generally forecast a much higher rise due to accelerated melting of polar glaciers as well as increased warming of ocean surface layers. Both may be related to increased amounts of carbon dioxide in the atmosphere (4). The National Ocean Service, which prepares the official U.S. tide predictions (5), periodically updates its datum to conform to values observed over a 19-yr period. The predictions used in this study from 1985 on are based on a new 1960–1978 epoch. However, predicted tides appearing herein may be as much as several tenths of a foot (0.03–0.09 m) lower than they should be by the end of the 1983–2000 period, depending on the actual sea level rise after 1980.

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Extreme Range of Tides

Spring tides are large semidaily tides that occur twice a month near full and new moons when the lunar and solar attractions are superimposed. Perigean tides are large semidaily tides that occur monthly when the moon is closest to the earth. Tropic tides are large diurnal tides that occur twice a month when the moon is at extreme north or south declination. These and other variations such as perihelion (earth annually closest to the sun) and some perigees with the moon closer to the earth than others are included in tide prediction by appropriate tidal constituents. Furthermore, the amplitudes of lunar constituents are modulated over a cycle of 18.61 yr to account for the longitude of the moon's node, the intersection of the lunar orbit with the plane of the ecliptic.

Obviously, tides will be particularly high when spring tides coincide with perigean tides, tropic tides, perihelion, and so forth. Since these various cycles are incommensurable, tide predictions are never exactly duplicated. Tidal mathematicians use future astronomical data to estimate when a combination of spring, perigee, etc. will cause particularly high tides (2,6). These special studies, however, apply to semidiurnal tidal regimes and are, therefore, not as applicable to the California coast, which has a significant diurnal component. The standard tide prediction methods are the only reasonable way of estimating dates of unusual high tides for California, and this has now been done for San Diego, Los Angeles, San Francisco, and Humboldt Bay.

Tables of Predicted Extreme High Tides

Tables 1–4 furnish monthly and annual extreme high tide predictions for 1983–2000. With the exception of Humboldt Bay where the 1983–1984 predictions refer to a different location than the 1985–2000 predictions, the range between annual extreme highs is only 0.4 ft (0.12 m) and the same is true for Humboldt Bay, 1985–2000. The two years that occur on the extreme high lists for all four stations are 1986 and 1990. The period of 1986–1990 represents a portion of the 18.61 yr lunar node cycle where the amplitudes of the lunar diurnal constituents are increased the most. (The diurnal amplitudes are essentially proportional to the sine of the lunar declination, which varies between 23.4° +/− 5.1° during the node cycle.) During these years, the amplitude of the principal semidiurnal constituents is reduced the most, bringing out the weakness an applying semidaily criteria to mixed tides.

Fig. 1 shows a plot of the monthly maxima at the four locations, 1983 and 1984 being omitted for Humboldt Bay because the predictions for these years are for a different (nearby) location. There is a marked semiannual beat due to the semidiurnal constituents S2 and K2 being two cycles per year different in frequency and the diurnal components K1 and P1 having the same frequency separation. This completely obscures the semiannual variation in sea level (Ssa, range 0.1–0.2 ft or 0.03–0.06 m) and masks the annual variability (Sa, range 0.4–0.5 ft or 0.12–0.15 m). There is also an obvious cyclical variability of about 4.4 yr, which is ascribed to "passages of the longitude of (lunar) perigee past the equinoxes," (2) either vernal or autumnal. This phenomenon causes 4.4 yr

TABLE 1.—San Diego Predicted Extreme High Tides, 1983–2000[a]

Year (1)	January (2)	February (3)	March (4)	April (5)	May (6)	June (7)	July (8)	August (9)	September (10)	October (11)	November (12)	December (13)	Annual Maximum Height (14)	Annual Maximum Date (15)
1983	7.6	7.2	6.4	6.4	6.6	7.2	7.6	7.7	7.4	6.7	7.0	7.2	7.7	August 7, 8
1984	7.5	7.3	6.8	6.6	7.0	7.1	7.4	7.4	6.9	7.3	7.5	7.4	7.5	January 18, November 22, 23
1985	7.0	7.1	6.8	6.6	7.1	7.4	7.5	7.1	6.8	7.1	7.6	7.7	7.7	December 11, 12
1986	7.5	7.1	6.5	6.9	7.3	7.7	7.7	7.5	6.8	6.7	7.3	7.8	7.8	December 31
1987	7.6	7.0	6.2	6.4	6.9	7.4	7.7	7.8	7.3	6.8	7.2	7.5	7.8	August 8
1988	7.6	7.3	6.6	6.7	6.9	7.3	7.6	7.4	7.0	7.4	7.4	7.2	7.6	January 19, July 28
1989	7.2	7.2	6.7	6.8	7.2	7.3	7.3	7.1	6.8	7.4	7.7	7.7	7.7	November 13, December 12
1990	7.4	6.9	6.6	7.1	7.5	7.6	7.6	7.2	6.5	7.0	7.5	7.8	7.8	December 2, 31
1991	7.7	6.7	6.1	6.6	7.1	7.6	7.8	7.6	7.0	6.9	7.4	7.6	7.8	July 11
1992	7.6	7.2	6.4	6.6	6.9	7.5	7.6	7.3	7.0	7.3	7.3	7.1	7.6	January 19, July 28, 29
1993	7.3	7.2	6.6	6.8	7.1	7.2	7.1	7.1	6.9	7.4	7.6	7.5	7.6	November 13, 14
1994	7.1	6.6	6.6	7.0	7.4	7.5	7.3	6.9	6.5	7.0	7.5	7.7	7.7	December 2, 3
1995	7.6	6.5	6.2	6.6	7.1	7.5	7.6	7.4	6.8	7.0	7.4	7.6	7.6	January 1, July 11, December 21, 22
1996	7.5	7.0	6.3	6.3	6.9	7.5	7.6	7.3	6.7	7.0	7.0	7.2	7.6	July 29
1997	7.4	7.3	6.7	6.5	6.8	6.9	7.3	7.3	6.9	7.1	7.3	7.3	7.4	January 9
1998	7.0	6.8	6.4	6.9	7.2	7.3	7.2	7.0	6.9	6.9	7.3	7.6	7.6	December 3
1999	7.5	6.7	6.4	6.5	7.1	7.5	7.6	7.4	6.8	7.0	7.5	7.7	7.7	December 22
2000	7.6	7.1	6.4	6.0	6.8	7.5	7.7	7.4	6.7	6.7	7.4	7.0	7.7	July 30

[a]In feet above chart datum.

Note: Highest = 7.8 ft in 1986, 1987, 1990, 1991; for 1983–1984, datum below mean sea level by 2.93 ft; for 1985–2000, datum below mean sea level by 2.94 ft.

TABLE 2.—Los Angeles Predicted Extreme High Tides, 1983–2000[a]

Year (1)	January (2)	February (3)	March (4)	April (5)	May (6)	June (7)	July (8)	August (9)	September (10)	October (11)	November (12)	December (13)	Annual Maximum	
													Height (14)	Date (15)
1983	7.1	6.7	5.9	5.9	6.1	6.7	7.1	7.2	6.9	6.2	6.5	6.7	7.2	August 8
1984	6.9	6.8	6.3	6.1	6.4	6.6	6.9	6.9	6.5	6.7	7.0	6.9	7.0	November 23
1985	6.5	6.6	6.3	6.1	6.6	6.9	7.0	6.6	6.4	6.6	7.1	7.2	7.2	December 11, 12
1986	7.1	6.6	6.0	6.4	6.8	7.2	7.2	7.0	6.4	6.2	6.8	7.3	7.3	December 31
1987	7.1	6.6	5.7	5.9	6.4	6.9	7.2	7.3	6.8	6.3	6.7	7.0	7.3	August 8
1988	7.1	6.8	6.2	6.2	6.4	6.8	7.1	6.9	6.5	6.9	7.0	6.8	7.1	January 19, July 28
1989	6.7	6.7	6.3	6.3	6.7	6.8	6.8	6.7	6.3	6.9	7.2	7.2	7.2	November 13, December 12
1990	6.9	6.4	6.1	6.6	7.0	7.1	7.1	6.7	6.1	6.5	7.0	7.3	7.3	December 2, 31
1991	7.2	6.2	5.6	6.1	6.6	7.0	7.2	7.1	6.5	6.5	6.9	7.1	7.2	January 1, July 10, 11
1992	7.1	6.7	5.9	6.1	6.5	6.9	7.0	6.8	6.5	6.8	6.8	6.7	7.1	January 19
1993	6.8	6.7	6.1	6.3	6.6	6.7	6.7	6.7	6.4	6.9	7.1	7.0	7.1	November 13, 14
1994	6.7	6.2	6.1	6.5	6.9	7.0	6.8	6.4	6.1	6.6	7.0	7.2	7.2	December 2, 3
1995	7.1	6.0	5.7	6.1	6.6	7.0	7.1	6.9	6.3	6.5	6.9	7.1	7.1	January 1, July 11, December 21, 22
1996	7.0	6.5	5.8	5.8	6.4	7.0	7.1	6.8	6.2	6.5	6.5	6.7	7.1	July 29
1997	6.9	6.8	6.3	6.0	6.3	6.5	6.8	6.8	6.5	6.6	6.8	6.8	6.9	January 9
1998	6.6	6.3	5.9	6.3	6.7	6.8	6.7	6.5	6.4	6.4	6.8	7.1	7.1	December 3
1999	7.0	6.3	6.0	6.1	6.6	7.0	7.1	6.9	6.4	6.5	7.0	7.2	7.2	December 22
2000	7.1	6.6	5.9	5.6	6.3	7.0	7.2	6.9	6.3	6.2	6.5	6.9	7.2	July 30

[a]In feet above chart datum.

Note: Highest = 7.3 ft in 1986, 1987, 1990; for 1983–1984, datum below mean sea level by 2.81 ft; for 1985–2000, datum below mean sea level by 2.84 ft.

TABLE 3.—San Francisco Predicted Extreme High Tides, 1983–2000

Year (1)	January (2)	February (3)	March (4)	April (5)	May (6)	June (7)	July (8)	August (9)	September (10)	October (11)	November (12)	December (13)	Annual Maximum	
													Height (14)	Date (15)
1983	7.1	6.6	5.9	5.8	6.0	6.5	6.9	7.0	6.6	6.0	6.4	6.8	7.1	January 27, 28
1984	7.0	6.8	6.2	6.0	6.3	6.5	6.7	6.6	6.2	6.5	6.8	7.0	7.0	January 18, December 21
1985	6.9	6.7	6.3	6.2	6.5	7.0	7.0	6.5	6.3	6.6	7.0	7.3	7.3	December 11, 12
1986	7.3	6.9	6.2	6.4	6.8	7.1	7.2	6.9	6.3	6.3	6.8	7.4	7.4	December 30, 31
1987	7.2	6.6	5.8	6.0	6.4	6.9	7.2	7.1	6.6	6.3	6.7	7.1	7.2	January 1, 28, 29 July 10
1988	7.2	6.9	6.1	6.1	6.3	6.8	6.9	6.7	6.4	6.7	6.9	7.0	7.2	January 18
1989	6.8	6.7	6.2	6.4	6.6	6.9	6.9	6.5	6.5	6.8	7.1	7.3	7.3	December 12
1990	7.1	6.7	6.3	6.6	6.9	7.1	7.1	6.7	6.3	6.6	7.0	7.4	7.4	December 31
1991	7.2	6.4	6.0	6.2	6.6	7.0	7.1	7.0	6.4	6.5	6.9	7.2	7.2	January 1, December 21, 22
1992	7.2	6.7	6.0	6.1	6.4	6.8	6.9	6.6	6.4	6.7	6.8	6.8	7.2	January 19
1993	6.9	6.7	6.2	6.3	6.5	6.7	6.7	6.5	6.5	6.8	7.0	7.2	7.2	December 12
1994	7.0	6.5	6.3	6.5	6.8	6.9	6.9	6.5	6.3	6.6	6.9	7.3	7.3	December 31
1995	7.2	6.3	6.0	6.2	6.6	6.9	7.0	6.9	6.3	6.5	6.9	7.2	7.2	January 1, December 21, 22
1996	7.1	6.7	6.0	5.9	6.4	6.9	6.9	6.6	6.2	6.4	6.6	6.8	7.1	January 19, 20
1997	7.0	6.8	6.3	6.0	6.2	6.5	6.7	6.7	6.3	6.5	6.8	6.9	7.0	January 8, 9
1998	6.8	6.4	6.1	6.3	6.6	6.8	6.8	6.5	6.2	6.4	6.8	7.1	7.1	December 3, 31
1999	7.1	6.4	6.1	6.2	6.5	6.9	7.0	6.9	6.4	6.5	7.0	7.2	7.2	December 22, 23
2000	7.2	6.8	6.1	5.8	6.3	7.0	7.1	6.8	6.2	6.1	6.5	7.0	7.2	January 20

[a]In feet above chart datum.

Note: Highest = 7.4 ft in 1986, 1990; for 1983–1984, datum below mean sea level by 3.05 ft; for 1985–2000, datum below mean sea level by 3.13 ft.

TABLE 4.—Humboldt Bay Predicted Extreme High Tides, 1983–2000[a]

Year (1)	January (2)	February (3)	March (4)	April (5)	May (6)	June (7)	July (8)	August (9)	September (10)	October (11)	November (12)	December (13)	Annual Maximum	
													Height (14)	Date (15)
1983	8.1	7.6	6.6	6.6	6.9	7.3	7.6	7.6	7.2	6.9	7.3	7.8	8.1	January 28, 29
1984	8.0	7.8	7.1	7.0	7.1	7.2	7.4	7.2	7.0	7.4	7.8	7.9	8.0	January 18, 19
1985	7.8	7.8	7.6	8.0	8.3	8.4	8.3	7.5	7.6	8.1	8.5	8.6	8.6	December 11, 12
1986	8.3	7.9	7.7	8.1	8.5	8.6	8.4	7.9	7.3	7.7	8.2	8.6	8.6	June 21, December 30, 31
1987	8.4	7.8	7.3	7.7	8.1	8.4	8.4	8.2	7.7	7.6	8.0	8.3	8.4	January 1, June 12, July 10, 11
1988	8.4	8.0	7.7	7.9	8.0	8.1	8.1	7.8	7.9	8.2	8.3	8.1	8.4	January 19
1989	8.0	7.9	7.8	8.1	8.3	8.3	8.1	7.6	7.9	8.3	8.5	8.5	8.5	November 13, 14 December 11, 12
1990	8.1	7.6	7.9	8.3	8.5	8.5	8.2	7.7	7.5	7.9	8.4	8.6	8.6	December 2, 3, 31
1991	8.4	7.5	7.5	7.9	8.2	8.5	8.4	8.1	7.4	7.8	8.2	8.4	8.5	June 12
1992	8.3	7.9	7.6	7.8	7.9	8.2	8.1	7.7	7.9	8.1	8.1	7.9	8.3	January 19
1993	8.0	7.9	7.8	8.0	8.2	8.1	7.9	7.6	7.9	8.2	8.4	8.4	8.4	November 13, 14 December 12
1994	8.0	7.4	7.9	8.3	8.4	8.3	8.0	7.4	7.5	8.0	8.4	8.5	8.5	December 2, 3
1995	8.3	7.3	7.5	7.9	8.2	8.4	8.3	7.9	7.4	7.9	8.3	8.4	8.4	June 12, 13 December 21, 22
1996	8.3	7.9	7.3	7.5	7.9	8.3	8.2	7.8	7.5	7.7	7.8	8.0	8.3	January 19, 20 June 30
1997	8.2	8.1	7.6	7.7	7.9	7.9	7.9	7.8	7.6	7.9	8.1	8.1	8.2	January 9
1998	7.8	7.7	7.7	8.0	8.2	8.2	7.9	7.5	7.4	7.8	8.2	8.4	8.4	December 3, 4
1999	8.3	7.6	7.4	7.9	8.2	8.4	8.3	7.9	7.4	7.9	8.4	8.5	8.5	December 22, 23
2000	8.4	7.9	7.2	7.4	7.9	8.4	8.5	7.9	7.2	7.4	7.9	8.3	8.5	July 1

[a]In feet above chart datum.

Note: Highest = 8.6 ft in 1985, 1986, 1990; for 1983–1984 for South Jetty (40° 45′ N, 124° 14′ W), datum below mean sea level by 3.45 ft; for 1985–2000 for North Spit (40° 46′ N, 124° 13′ W), datum below mean sea level by 3.70 ft.

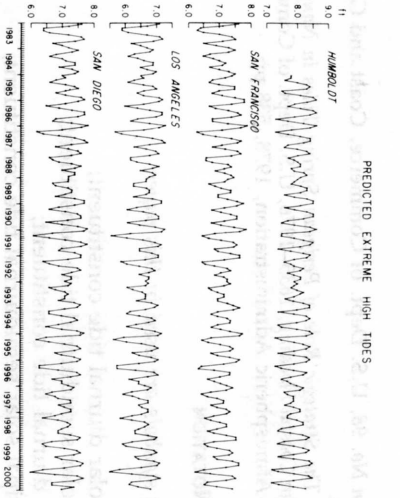

FIG. 1.—Plots of Predicted Extreme High Tides Relative to Respective Chart Datum as Tabulated in Tables 1–4

beats in the extreme lowest tides as well, and has been cited as a complication in choosing realistic chart data (3). Finally, the 18.61-yr node cycle is apparent with highest annual maxima in the 1986–1990 period and lowest annual maxima 9 yr later.

Conclusions

The predictions in Tables 1–4 will provide a measure of reassurance to those concerned with California's coastal zone and should be useful in the design of protective structures and other coastal engineering projects. Tremendous high tides are not predicted for the remainder of this century. Nevertheless, the highest tides in the period 1986–1990 will be slightly higher than those of winter 1982–1983 due to enhancement of the diurnal lunar constituents in the 1986–1990 period of the moon's node cycle.

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Appendix II.—Notation

The following symbols are used in this paper:

K1 = lunisolar diurnal tide constituent;
K2 = lunisolar semidiurnal tide constituent;
P1 = solar diurnal tide constituent;
S2 = principal solar semidiurnal tide constituent;
Sa = solar annual tide constituent; and
Ssa = solar semiannual tide constituent.